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IOP Conf. Series: Journal of Physics: Conf. Series **800** (2017) 012041 doi:10.1088/1742-6596/800/1/012041

Upgrade of In-Beam Charged Particle Detector for the KOTO Experiment

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Abstract. The KOTO experiment aims at measuring the branching ratio of the $K_L \to \pi^0\nu\bar{\nu}$ decay. Since the decay is highly suppressed in the Standard Model, it is sensitive to new physics beyond the standard model. In the KOTO experiment, two photons from the π^0 in the final state are detected by an electromagnetic calorimeter, and the absence of extra particles except for the escaping neutrinos is ensured by the surrounding veto counters. As one of the veto counters, an in-beam charged particle detector, composed of 3-mm thick plastic scintillators, covered the beam hole of the calorimeter. It was operating in a high-rate environment with a single counting rate of 10 MHz, which caused 10% loss to the $K_L \to \pi^0\nu\bar{\nu}$ signal. To reduce the hits by neutral particles, the detector has been upgraded to a thin-gap wire chamber. Keeping a high detection efficiency over 99.6% for penetrating charged particles, a 65% reduction of the single counting rate was achieved, corresponding to 40% recovery of acceptance for $K_L \to \pi^0\nu\bar{\nu}$.

1. Introduction

1.1. KOTO experiment

The KOTO experiment aims at discovering a CP-violating rare decay of the long-lived neutral K meson, $K_L \to \pi^0\nu\bar{\nu}$. The branching ratio has been calculated as $(3.00 \pm 0.30) \times 10^{-11}$ with a small theoretical uncertainty[1] in the Standard Model. This smallness of the branching ratio makes the decay mode sensitive to the contribution of new physics beyond the Standard Model.

Figure 1 shows a cross-sectional view of the detector system used in the KOTO experiment. In this figure, a K_L comes into the detector system and decays to $\pi^0\nu\bar{\nu}$. The two photons from π^0 are measured with an electromagnetic calorimeter made of undoped cesium iodide crystals, named CsI, and the other detectors ensure no existence of extra particles other than neutrinos.

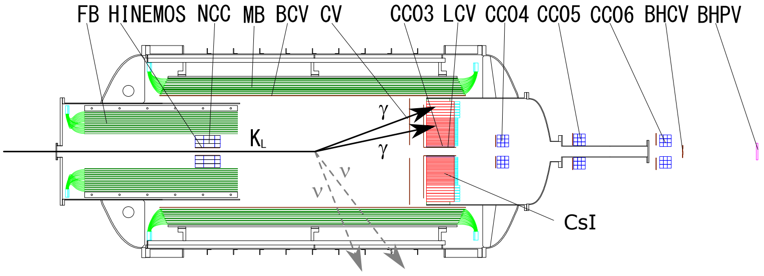

Figure 1. Cross-sectional view of the KOTO detectors.

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1.2. Upgrade of the in-beam charged particle detector

A charged particle detector, called Beam Hole Charged Veto (BHCV), is located at the downstream of the electromagnetic calorimeter. The role of BHCV is to suppress the $K_L \to \pi^+\pi^-\pi^0$ background where charged pions, π^+ and π^-, escape through the beam hole of the calorimeter as shown in figure 2. Due to the high flux of neutrons and gammas in the K_L beam, its single counting rate reached around 10 MHz when 3-mm-thick plastic scintillators were used as BHCV. Since the measurement of $K_L \to \pi^0\nu\bar{\nu}$ requires no in-time hit in any veto counter, accidental hits in BHCV caused a 10% loss of signal acceptance. To reduce the acceptance loss, BHCV was upgraded to three layers of thin-gap wire chambers, as shown in figure 3, which is more insensitive to neutral particles than the plastic scintillators. Its specification is summarized in table 1.

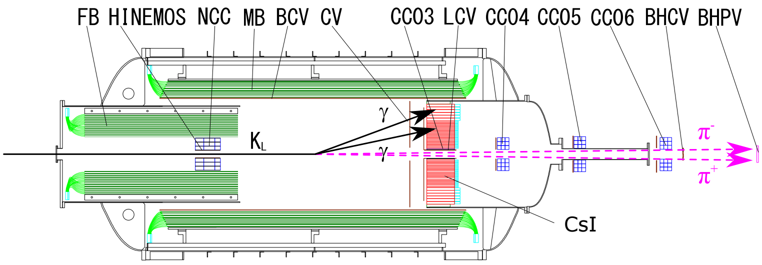

Figure 2. Example of the $K_L \to \pi^+\pi^-\pi^0$ background related to BHCV.

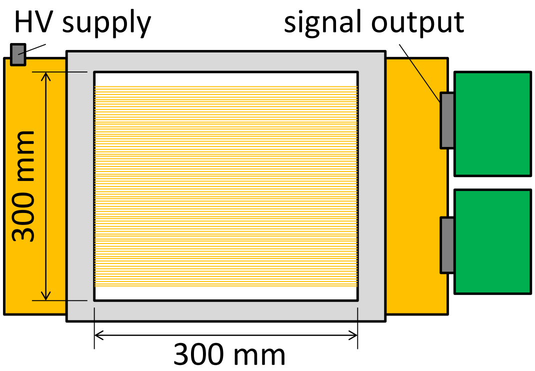

Figure 3. Outline of the wire chamber for BHCV.

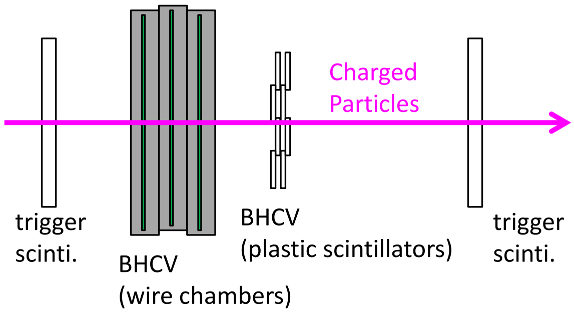

Figure 4. Set up for efficiency measurement. In addition to the plastic sintillators of previous BHCV, two trigger scintillators were used to make coincident trigger.

Table 1. Specification of the wire chamber.

wire diameter/length	50 μm / 30 cm
number of wires	160 (10 wires/channel)
wire-wire spacing	1.8 mm
wire-cathode gap	1.4 mm
cathode plane	graphite-coated kapton film 50-μm thick
gas	CF_4:n-pentane = 55:45
operation voltage	2.7 kV
capacitance per channel	50 pF

2. Study of Detector performance

2.1. Detection efficiency and background suppression

Figure 4 shows a set up of efficiency measurement of the wire chamber for BHCV. To select penetrating charged particles, two additional plastic scintillators were located at the upstream and downstream of BHCV. A distribution of energy deposition in one of the wire chambers is shown in figure 5. The resultant efficiency was over 99.6% in all the three wire chambers. Considering the detector performance of the wire chambers, the background suppression power for $K_L \to \pi^+\pi^-\pi^0$ was estimated by using Geant4 [2] based Monte Carlo simulation. As a result, the background reduction of the wire chambers was the same as the plastic scintillators.

2.2. Single counting rate

The single counting rate was measured in both the plastic scintillators and the wire chambers during physics data taking in 2015. Figure 6 shows the single counting rate with respect to the beam power. The wire chambers had a 65% lower counting rate than that of the plastic scintillators. Although the wire chambers need to use a longer veto timing window of 25 ns to confirm extra particle existence, due to large timing fluctuation coming from drift time of discharged electrons, compared to the 15-ns of the plastic scintillators, the resultant acceptance loss for $K_L \to \pi^0\nu\bar{\nu}$ was reduced by 40%[1].

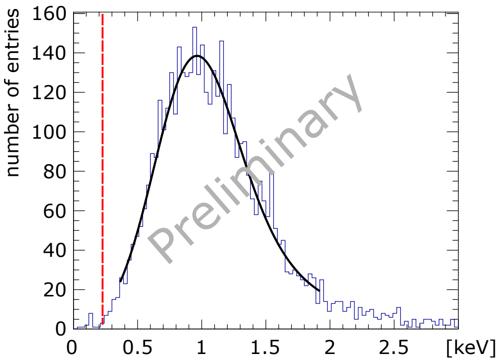

Figure 5. Energy deposit in a single wire chamber. The red dashed line shows a quarter of the peak used as threshold for efficiency calculation.

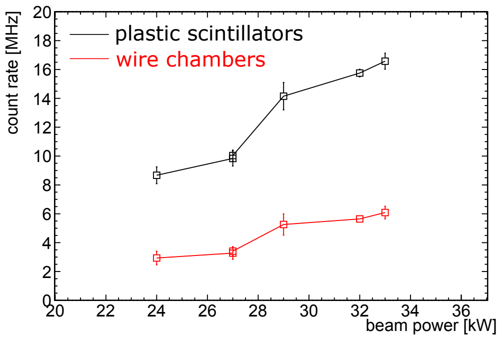

Figure 6. Single counting rate of BHCV with respect to the beam power.

3. Conclusion

In the KOTO experiment, an in-beam charged particle veto, named as BHCV, was upgraded from the plastic scintillators to the three layers of thin-gap wire chambers to suppress the acceptance loss for $K_L \to \pi^0\nu\bar{\nu}$ due to high rate accidental hits by neutral particles. Its single counting rate was reduced by 65% and the resultant acceptance loss of $K_L \to \pi^0\nu\bar{\nu}$ became 40% lower without changing its background reduction ability owing to the high detection efficiency over 99.6% in each single wire chamber.

References

[1] A J Buras, D Buttazzo, J Girrbach-Noe and R Knegjens 2015 *J. High Energy Phys.* **033** 1511.
[2] S AgostinelliA *et al* 2003 *Nucl. Instr. Meth. Phys. Res. A* **506** 250-303.

[1] Acceptance loss due to accidental hits in a veto counter can be calculated by multiplying its counting rate and timing window.